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XV.

ON TELEPHONING OVER LONG DISTANCES OR THROUGH CABLES.

By N. D. C. Hodges.

Presented May 10, 1882.

The first point I wish to bring up is, that within any conductor connected with the earth the only electrical forces against which work has to be done during the movement of electrified bodies are those due to the mutual actions between the charges in these bodies, and not to the charges which may exist outside the conducting surface. So that in causing a movement of electricity from A to B, the work is the same when A and B are inside a conducting surface as when they are outside; and to cause a current along any course from A to B, the same amount of energy will be required as if the system $A\ B$ were in open space.

Hence in the case of a double-wire cable of no great length compared with its section, so that the resistance of the wire should not be sufficient to cause it to act like a succession of short pieces, the source of the electromotive force being contained in a conducting surface continuous with the outside of the cable, a current could be produced as easily as in an air-line.

In the next place, in the case of a cable we have a condenser to deal with, the circuit wire being the inner, and the water outside the outer surface. In order to cause a current to flow through a conductor situated in this way, a quantity of electricity must be supplied sufficient to raise the potential along the conductor to such a degree that the required current may flow.

To raise the charge of a conductor, the work to be done is expressed by $\frac{1}{2}\,\varepsilon V$, where ε is the final charge of the conductor and V its potential; or, in terms of the capacity and potential, $\frac{1}{2}\,q V^2$.

For a single wire surrounded by a homogeneous non-conductor to an indefinite distance, the electric capacity is $\frac{1}{2}\frac{l}{\log\frac{l}{a}}$, where l is the length of the wire and a its radius.

For a wire surrounded by a homogeneous dielectric to a limited distance, the capacity is $\frac{1}{2}\frac{Kl}{\log\frac{a_1}{a_2}}$, where K is the specific inductive capacity of the dielectric, and a_1 and a_2 the outer and inner radii of the dielectric.

As the energy required to charge a condenser is

$$W = \tfrac{1}{2} q V^2,$$

and as no work is done in moving the one conducting surface within the other, the same expression for the work done in charging a cable will hold when the wire is not concentric with the outside as when it is, as was supposed in the above.

Hence the work required to charge a unit length of cable, even when the wires are not in the centre, will be equal to

$$W = \tfrac{1}{2} q V^2 = \tfrac{1}{2} \frac{K}{\log\frac{a_1}{a_2}} V^2.$$

On account of this static capacity of a cable, there is a retardation in the transmission of signals from the greater amount of energy which must be supplied from the electrical source before the potential along the wire will be raised sufficiently to cause the required current; just as, in the case of heat, the specific heat of a bar determines how much heat must be given to one end of the bar before heat will flow along the bar at any given rate.

With a single wire cable let V be the potential at any point of the wire. Let Q be the total quantity of electricity which has passed through a section of the cable at that point since the beginning of the current. Then the quantity which at the time t exists between sections at x and $x + \delta x$ is

$$Q - \left(Q + \frac{dQ}{dx}\delta x\right) \text{ or } -\frac{dQ}{dx}\delta x$$

and this is equal to $q V \delta x$.

Hence $$qV = -\frac{dQ}{dx}.$$

With a double-wire cable when used to form a metallic circuit, the two wires being connected to the two poles of the battery or transmitter, or whatever the electric source may be, the quantity of electricity flowing across any section of the cable on one of the wires will be equal and of opposite sign to that on the other.

Hence the total quantity flowing across any section of the cable will be zero, and dQ will be zero. So that the potential to which the condenser, consisting of the two wires and the outside surface of the cable, will be raised will be zero, and the energy required from the battery no greater on account of the nearness of the water, the second conducting surface of the condenser.

There is one thing to be considered, that the wires, being covered with some insulating material which cannot be made perfectly homogeneous, they, with the broken nature of the dielectric about them, will each form a condenser to some extent.

It would therefore appear that, as far as the retardation is due to the static capacity of a cable, it can be greatly reduced by using a double wire cable with homogeneous insulating material.

In support of this view there are the experiments made by Wheatstone, and described in the Proceedings of the Royal Society for 1854–55. Wheatstone made experiments on a cable of six wires intended for use in the Mediterranean. The length of the cable was one hundred and ten miles. On connecting one of the wires with one pole of his battery, the other pole being to ground, he found that quite a time was required before the flow into the cable fell to the rate due to leakage. On connecting one pole of the battery with one wire and the other with another, the charge which the cable wires would take was reached instantly.

On long land lines the static capacity of the line is due, outside of the capacity of the wire, to the neighborhood of the earth. This has been found to affect the articulation in telephoning on the line from Boston to Baltimore, five hundred miles in length. By the use of a complete metallic circuit the articulation was greatly improved.

SALEM, MASS., U. S. A.,
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